Recent Trends of Mean Maximum and Minimum Air Temperatures in Bangladesh

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ABSTRACT

The annual, seasonal, and monthly maximum and minimum air temperature time series for 34 stations in Bangladesh have been examined during the period 1981–2020 in this study. Three statistical tests were used in the analysis namely Mann–Kendall, Sen's slope estimator, and linear regression, respectively. 47% of stations experienced significantly rising maximum air temperature trends during the pre-monsoon, 100% during the monsoon, 74% during the post-monsoon, and 24% during the winter season, respectively. Similar findings have been made about minimum air temperatures during the pre-monsoon, monsoon, post-monsoon, and winter seasons in 41, 91, 41, and 35% of stations over Bangladesh. According to the linear regression technique, the significant increasing trends of the maximum air temperatures at Patuakhali and Mongla stations are 0.83 °C/decade and 0.82 °C/decade in February and October, respectively. Furthermore, at Sandwip and M. Court, the significant increasing minimum air temperature trends in July and March are 0.26 °C/decade and 0.66 °C/decade, respectively. The highest monthly maximum and minimum air temperature time series value falls (decreases) were seen in January over the stations at Mongla (-0.58 °C/decade) and Sandwip (-0.63 °C/decade), respectively. This information will be useful in developing adaptation plans to mitigate the harmful effects of climate change. Vulnerability assessments, disaster management, enhanced structure design, institutional reform, and anti-extreme climate engineering are some of the viable climate change adaptation approaches in Bangladesh due to rising temperatures.

Keywords: Mann–Kendall test, Sen's slope estimator, Linear regression, Temperature.

1. INTRODUCTION

Bangladesh's topography is mostly flat, with some hills in the northeast and southeast regions. Bangladesh's climate is subtropical monsoon, with considerable seasonal variations in rainfall, high temperatures, and humidity. Bangladesh has four different seasons: a hot, humid pre-monsoon season (March to May), a wet or rainy summer monsoon season (June to September), a transitional post-monsoon season (October to November) between the summer monsoon and the winter, and a cold, dry winter (December to February). The range of 35 °C to 41 °C is regularly experienced for pre-monsoon maximum temperatures. April is the warmest month in most regions of the country. January is the coldest month, with an average temperature of roughly 13 °C across the country (BMD 2016).

Bangladesh is among the top ten countries in the world that would be severely impacted by climate change (Eckstein *et al.* 2017). Experts expect that global climate change will trigger substantial changes in temperature and rainfall patterns across the country. As a result, extreme weather events are to be anticipated (Shahid 2010, 2011; Khan *et al.* 2019). Global warming is responsible for both global (Lambert *et al.* 2003; Dore 2005) and regional climate change (Gemmer *et al.* 2004; Kayano & Sansigolo 2008). Climate change has a disproportionate impact on already-stressed regions, such as Bangladesh, where hydrological disasters are prevalent (Shahid & Behrawan 2008). According to the Intergovernmental Panel on Climate Change (IPCC), Bangladesh is among the most vulnerable countries in the world to climate change (IPCC 2007).

One of the most contentious problems in recent time is the rise in global surface air temperature. Temperature is a key component of climatic fluctuation and change at the local, regional, and global levels (Islam 2009). Climate change research has been conducted in a variety of areas across the world (Jeganathan & Andimuthu 2012). The trends, on the other hand, vary according to seasonal and annual patterns, and are significantly influenced by height, proximity to the sea, and other geographical factors (Pal & Al-Tabbaa 2010). The tropical climate of Bangladesh coastal areas can be found in the country's southern and eastern regions (Sheikh *et al.* 2015). The climate of the coastal area is greatly impacted by the Indian Ocean and the Bay of Bengal (Shaman *et al.* 2005). According to Abdullah *et al.* (2020), both coastal and inland areas are warming significantly, although coastal areas are warming at a faster rate. Droughts and flash floods, on the other hand, are widespread in inland locations due to large hydro-climatic changes (Etzold *et al.* 2014; Dewan *et al.* 2019). Drought is also more widespread in the northwestern parts of the country (Khan *et al.* 2020). Temperature and extreme weather events have significant socioeconomic consequences, including direct implications on water availability and use, power generation and consumption, agricultural output, human health and comfort, and so on (Meehl *et al.* 2000). As a result, thorough effect assessments require data on climatic variability changes at the local, regional, and national levels. Because variability is crucial in interpreting climate change, researchers must examine changes in mean temperature (MT) as well as trends in climatic variables of variability (Jeganathan & Andimuthu 2012).

Numerous studies have described global and hemispheric trends in surface air temperature (IPCC 2001). According to the Third Assessment Report, the average temperature increase by 2100 would be between 1.4 and 5.8 degrees Celsius (IPCC 2001). While changes in global mean surface temperature are an essential indicator of climate change and unpredictability, taking other elements into consideration has helped researchers better understand the causes of some of the recent shifts (Shahid 2010). The temperature of a certain regions where surface varies annually and seasonally, depending on latitude and location in relation to physical features such as a water body (river, lake, or sea) (Jain & Kumar 2012). Monthly mean maximum and minimum temperatures are two more thermometric variables that have piqued the interest of scientists. This is because changes in maximum, minimum or both temperatures can cause oscillations in mean surface temperature (Braganza *et al.* 2004). Observed surface warming over the land has been linked to rising minimum and maximum temperatures during the last 50 years (Karl *et al.* 1993; Brazdil *et al.* 1996; Easterling *et al.* 1997; New *et al.* 2000; Foland *et al.* 2001; Jin & Dickinson 2002; Klein Tank & Konnen 2003; Tangborn 2003).

Despite the fact that there is a wealth of information on Bangladesh's rainfall patterns and climate (Ahmed & Karmaker 1993; Ahmed *et al.* 1996; Hussain & Sultana 1996; Kripalini *et al.* 1996; Ahmed & Kim 2003; Shahid 2008; Islam & Uyeda 2008), few studies on historical rainfall and temperature trends have been conducted (Rahman *et al.* 1997; Singh 2001; Jones 1995). Jones (1995) has so far completed the only investigation of temperature trends in Bangladesh. He examined the monthly mean maximum and minimum temperatures in Bangladesh using data from 1949 to 1989 and found no significant variations in the annual mean minimum and mean maximum temperatures. The mean maximum (TMAX) and mean minimum (TMIN) temperatures over Bangladesh were found to have significantly increased between 1981 and 2015, according to recent study by Imam *et al.* (2022). Findings from the border between India and Bangladesh are in conflict with it. Scientific studies on the variations in rainfall and temperature in India have been conducted by many scientists (Mooley & Parthasarathy 1984; Rupa Kumar *et al.* 1992; Pant & Rupa Kumar 1997; Arora *et al.* 2005; Guhathakurta and Rajeevan 2007). In India, winter temperatures have increased more rapidly than pre-monsoon temperatures during the past century, as per study by Guhathakurta and Rajeevan (2007).

Despite significant warming of minimum temperatures, maximum temperatures have only showed mild warming and cooling in various parts of the country and during most seasons (Jones 1995). Gadgil and Dhorde (2005) examined the temporal change in temperature over Pune, India from 1901 to 2000. According to their findings, the mean annual and maximum temperatures have both reduced dramatically. Su *et al.* (2006) used daily data from 108 meteorological stations to examine extreme temperature and precipitation trends along the Yangtze River from 1960 to 2002. Their findings revealed a positive trend in annual and seasonal mean maximum and minimum temperatures, with the Yangtze River's winter mean minimum temperature exhibiting the highest trend. Shahid (2010) recently examined mean maximum and mean minimum temperatures over Bangladesh from 17 meteorological sites from 1958 to 2007. Significant increases in mean maximum and mean minimum air temperatures of 0.10 °C/decade and 0.09 °C/decade, respectively, were also seen at a 95% level of confidence. The majority of the research has been conducted using data from before 1990, even though monsoon rainfall and temperature trends have been studied for 30 to 40 years in a number of locations in Bangladesh (Shahid 2010). These investigations might have missed recent climate change. As a result, the Mann-Kendall test, Sen's slope estimator, and linear regression were used to assess monthly, seasonal, and annual trends in mean maximum and minimum air temperatures in Bangladesh from 1981 to 2020.

2. DATA AND METHODOLOGY

Climate research requires reliable data and a long enough record to boost the validity of the results. For the period 1981–2020, a set of monthly mean maximum air temperature and mean minimum air temperature data from 34 meteorological stations of Bangladesh Meteorological Department were used in this study. Long period monthly mean maximum and mean minimum temperature were analysed in the present study to assess the recent change in the climate of Bangladesh. Monthly values were averaged to obtain seasonal and annual values. As per Bangladesh Meteorological Department, seasons were considered as follows: pre-monsoon = March–May; monsoon = June–September; post-monsoon = October–November and winter = December–February. The information about the stations is presented in Table 1 and location of Bangladesh Meteorological Department stations are shown in Fig. 1.

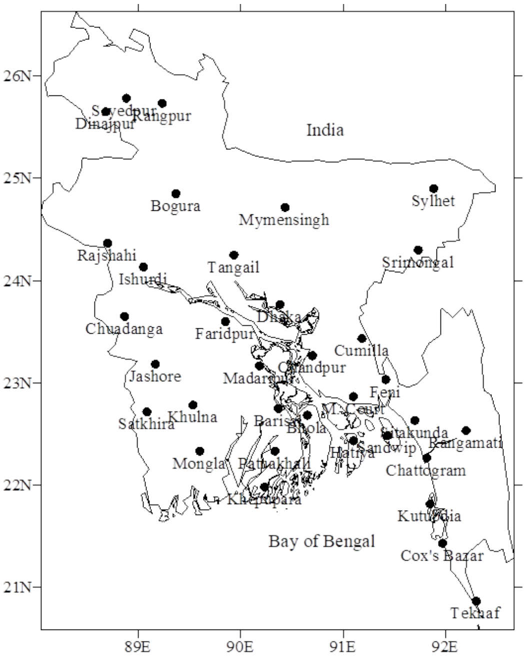

Fig. 1: Map showing the location of Bangladesh Meteorological Department observational sites.

Table. 1: Geographic characteristics of the Bangladesh Meteorological Department stations which was used in the study.

S. N.	Station Name	Longitude (E)	Latitude (N)	Altitude (M)
1	Barisal	90.37	22.75	2.1
2	Bhola	90.65	22.68	4.3
3	Bogura	89.37	24.85	18
4	Chandpur	90.7	23.27	5.6
5	Chattogram	91.82	22.27	5.5
6	Chuadanga	88.87	23.65	11.6
7	Cumilla	91.18	23.43	6.1
8	Cox's Bazar	91.97	21.43	2.1
9	Dhaka	90.38	23.77	8.8
10	Dinajpur	88.68	25.65	36
11	Faridpur	89.85	23.6	8.2
12	Feni	91.42	23.03	6.3
13	Hatiya	91.1	22.43	2.4
14	Ishurdi	89.05	24.13	14
15	Jashore	89.17	23.18	6.1
16	Khepupara	90.23	21.98	1.8
17	Khulna	89.53	22.78	2.1
18	Kutubdia	91.85	21.82	2.7
19	M. Court	91.1	22.87	4.9
20	Madaripur	90.18	23.17	7
21	Mongla	89.6	22.33	1.8
22	Mymensingh	90.43	24.72	18
23	Patuakhali	90.33	22.33	1.5
24	Rajshahi	88.7	24.37	16.8
25	Rangamati	92.2	22.53	62.5
26	Rangpur	89.23	25.73	32.6
27	Sandwip	91.43	22.48	2.1
28	Satkhira	89.08	22.72	4
29	Sayedpur	88.88	25.78	39.6
30	Sitakunda	91.7	22.63	7.3
31	Srimongal	91.73	24.3	22
32	Sylhet	91.88	24.9	33.5
33	Tangail	89.93	24.25	10.2
34	Teknaf	92.3	20.87	5

2.1 Magnitude of Trend

Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series (Lettenmaier *et al.* 1994; Yue & Hashino 2003; Partal & Kahya 2006). In this method, the slopes (Ti) of all data pairs are first calculated by

$$T_i = \frac{X_j - X_k}{j - k} \quad for\ i = 1,2,\ldots\ldots,N, \tag{1}$$

Where x_j and x_k are data values at time j and k (j > k), respectively. The median of these N values of T_i is Sen's estimator of slope, which is calculated as follows:

$$\beta = \begin{cases} \dfrac{T_N + 1}{2} & N\ is\ odd \\ \dfrac{1}{2}\left(T_{\frac{N}{2}} + \dfrac{T_{N+2}}{2}\right) & N\ is\ even \end{cases} \tag{2}$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

2.2 Significance of Trend

The statistical significance of the trend in monthly, seasonal and annual series were analysed using the non-parametric Mann-Kendall (MK) test (Mann 1945; Kendall 1975). The MK test has been employed by a number of researchers to ascertain the presence of statistically significant trend in hydrological climatic variables such as temperature, precipitation, and stream flow with reference to climate change. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

The statistic (S) is defined as (Salas 1993) follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i) \qquad (3)$$

Where N is the number of the data points. Assuming $(x_j - x_i) = \theta$, the value of sign (θ) is computed as follows:

$$\text{sign } (\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ \text{-}1 & \text{if } \theta < 0 \end{cases} \qquad (4)$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N > 10), the test is conducted using a normal distribution (Helsel & Hirsch 1992) with the mean and the variance is as follows:

$$E\,[S] = 0 \qquad (5)$$

$$\text{Var } (S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \qquad (6)$$

Where N is the number of tied (zero difference between compared values) groups and t_(k)the number of data points in the kth tied group. The standard normal deviate (Z-statistics) is then computed as (Hirsch *et al.* 1993) follows:

The standardized test statistic Z is given by:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \qquad (7)$$

If the computed value of |Z| > zα/2, the null hypothesis (H0) is rejected at α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% and 99% confidence level.

2.3 Linear Regression Method

Linear regression is a parametric statistical tool that is frequently used to investigate data trends over time. Trends may be covered in data dispersion coming from non-perfect hydrogeological circumstances, testing and examination conditions, and so on, if the traditional practice of translating the log slopes of the regression line is used. The most common strategy for detecting trends is to create a linear model between data and time.

Gadgil and Dhorde (2005) utilized linear regression to determine long-term changes in seasonal and annual rainfall. The mean temporal change in the studied variable is the fundamental statistical metric. A positive slope value denotes an upward tendency, whereas a negative one denotes a downward trend. The total change throughout the time period is calculated by multiplying the slope by the number of years (Tabari *et al.* 2010).

3. RESULTS AND DISCUSSION

The yearly, seasonal, and monthly patterns in the mean maximum and minimum temperature series were detected using the Mann–Kendall test, Sen's slope estimator, and linear regression. The results of the three statistical approaches have a high degree of resemblance. Fig. 2 shows the Mann–Kendall test findings for the annual mean maximum and minimum temperature series. Except for Satkhira, Chuadanga, Hatiya, Sandwip, Sitakunda, Rangamati and Patuakhali stations, the approaches identified increasing trends in yearly mean maximum and minimum air temperature. The statistical examines at twenty-eight and twenty stations out of 34 stations, found that the increasing mean maximum and minimum air temperature trends were significant at the 95% and 99% confidence levels, respectively. Only one station (Sandwip), negative minimum air temperature trends were significant, but negative maximum air temperature trends were non-significant. The magnitudes of the significant increasing trends in annual mean maximum air temperature varied from 0.15 °C/decade at Rangpur station to 0.53 °C/decade at Sandwip station, according to the linear regression approach. Similarly, annual mean minimum air temperature rates increased from 0.19 °C/decade at Mymensingh station to 0.38 °C/decade at Sylhet station. The rate of significant declining trends in annual mean minimum air temperature were -0.24 °C/decade at Sandwip station, but annual mean maximum air temperature was not found to be a negative significant trend. Fig. 3 and 4 illustrate the time series and linear trends of mean maximum and mean minimum air temperature at the stations with the most significant trends.

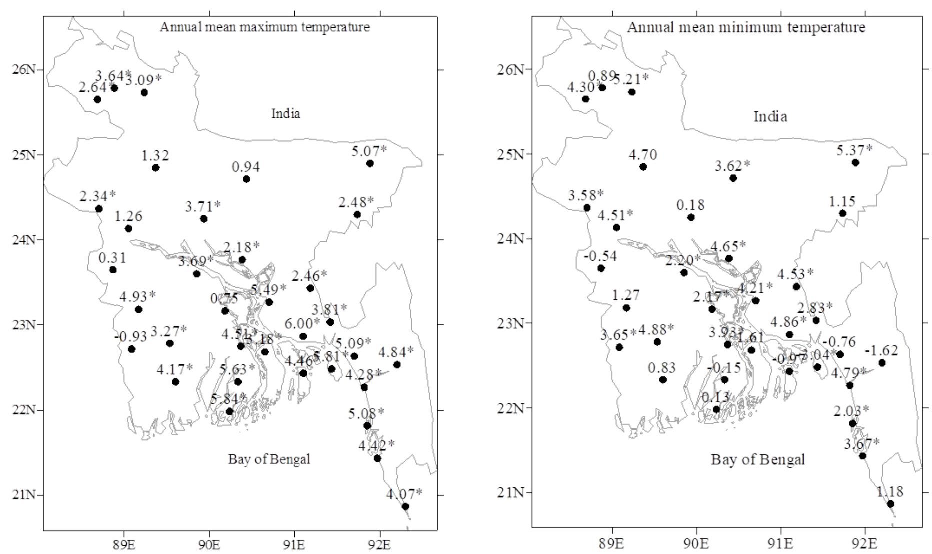

Fig. 2: Values of the statistics Z of the Mann-Kendall test for the annual maximum and minimum air temperature during 1981-2020. Star (*) values indicate significant trends.

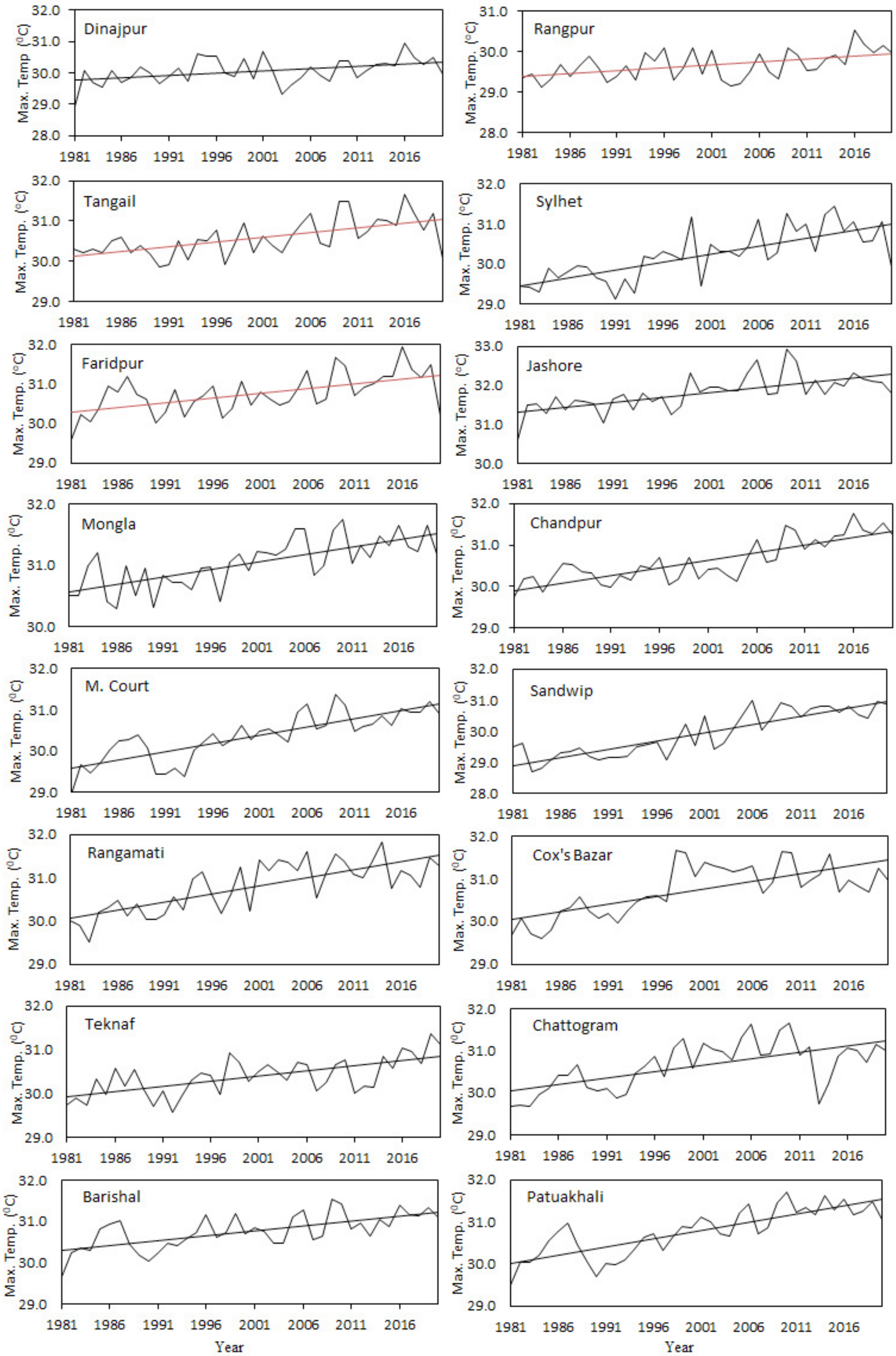

Fig. 3: Time series and linear trends of mean maximum air temperature at the stations with the most significant trends.

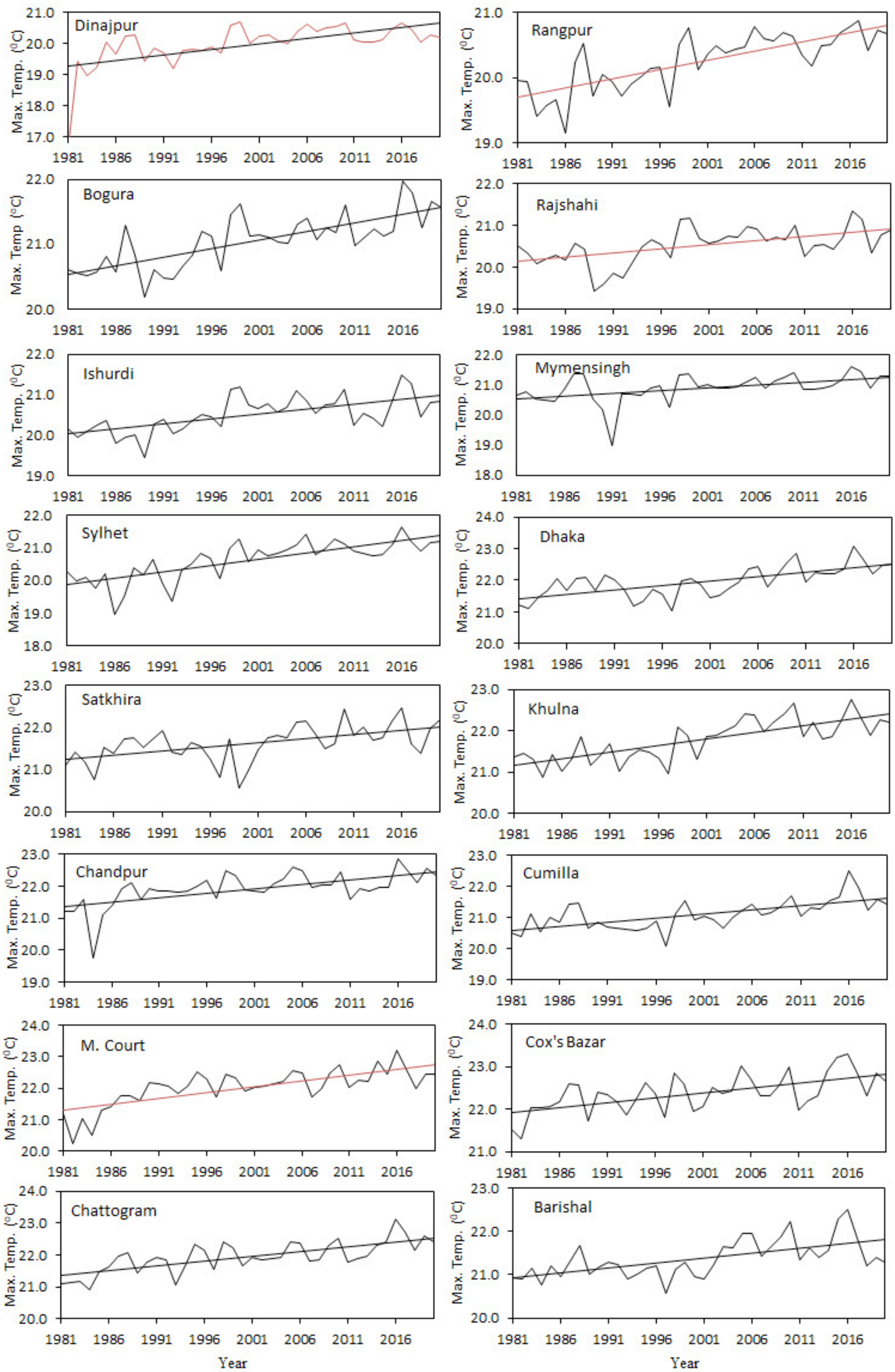

Fig. 4: Time series and linear trends of mean minimum air temperature at the stations with the most significant trends.

3.1 Seasonal and Monthly Analysis

Figs. 5-8 illustrate the results of the Mann–Kendall test on seasonal and monthly mean maximum and minimum air temperature data. The increasing mean maximum air temperature trends were detected in the pre-monsoon and monsoon seasons at 25 and 34 stations, and in the post-monsoon and winter seasons at 32 and 2 stations, respectively, based on the results of the three techniques. In pre-monsoon, monsoon, post-monsoon, and winter seasons, the increasing mean maximum air temperature trends were significant at 95% and 99% confidence levels for 16, 34, 25, and 8 stations, respectively. Furthermore, 27, 34, 25 and 22 stations exhibited positive trends in mean minimum air temperature data in pre-monsoon, monsoon, post-monsoon and winter, respectively. In pre-monsoon, monsoon, and post-monsoon, roughly 14, 31 and 13 stations, respectively, showed a significant increase in mean minimum air temperature, whereas only 12 stations were in winter. The significant increasing mean maximum air temperature trends varied between 0.21 ^{o}C/decade at Satkhira station and 0.60 ^{o}C/decade at Syedpur station in monsoon season, according to the linear regression approach. In addition, during monsoon season, substantial increases in mean minimum air temperature ranged from 0.12 ^{o}C/decade at Chuadanga station to 0.44 ^{o}C/decade at Dinajpur station. On the other hand, the most significant declines (decreases) in mean maximum and minimum air temperature values were seen at Satkhira and Sandwip stations in winter seasons at a rate of -0.35 ^{o}C/decade, and -0.51 ^{o}C/decade, respectively.

Monthly mean maximum and minimum air temperature series exhibited both increasing and decreasing tendencies, depending on the station, similar to the yearly and seasonal series. At the stations, the significant increasing mean maximum and mean minimum air temperature trends were larger than the significant declining (decreasing) ones.

In September and July, the highest number of stations with significant positive mean maximum and mean minimum air temperature trends occurred, accounting for 97% and 71% of all mean maximum and mean minimum air temperature stations, respectively (Fig. 7&8). On the other hand, the lowest number of stations with significant positive mean maximum and mean minimum air temperature trends was observed in the month of November and March, respectively (Fig. 7&8). These findings are in line with those of the seasonal analysis. The mean maximum and mean minimum air temperature series, on the other hand, experienced the highest number of significant positive trends in September and July (Fig. 7&8), respectively, during the period 1981-2020. In both monthly mean maximum and minimum air temperature series, exhibited a most significant positive trend, over Bangladesh. At Sylhet, Khulna, Chattogram and M. Court stations, all of the monthly mean minimum air temperature time series were significantly positive, but the most significant trends in the monthly mean maximum air temperature time series were noticed at Hatiya, Sandwip, and Sitakunda stations, respectively.

In addition, the monthly mean minimum air temperature series at Sandwip stations indicated statistically significant negative trends in pre-monsoon, post-monsoon and winter months, as well as some of the monsoon months and other stations almost showed significant positive trends in the mean minimum air temperature series.

Furthermore, the monthly mean maximum air temperature time series showed significant patterns in all stations, more or less. The significant increasing mean maximum air temperature trends, according to the linear regression technique, varied from 0.08 ^{o}C/decade at Patuakhali station in February to 0.82 ^{o}C/decade at Mongla station in October. Furthermore, significant increasing mean minimum air temperature trends varied from 0.03 ^{o}C/decade at Sandwip station in July to 0.67 ^{o}C/decade at M. Court station in March. On the other hand, the highest declines (decreases) in the monthly mean maximum and minimum air temperature time series values were observed over Mongla in January at -0.58 ^{o}C/decade and over Sandwip in January at -0.64 ^{o}C/decade, respectively. Mean maximum air temperature increased at a faster rate than that of mean minimum air temperature over the research period, according to the findings. These findings are in good agreement with the results of IPCC (2007).

According to the findings of this study, the observed warming trend over the last decades was primarily attributable to an increase in mean maximum air temperature rather than in mean minimum air temperature. The rise in mean maximum air temperature could be attributed to a number of variables, including global warming and higher quantities of manmade greenhouse gases, which trap heat and prevent it from leaving the Earth's atmosphere as well as increase urbanization. Overall, the mean maximum and mean minimum air temperature time series in the study area have shown warming tendencies in recent decades. The positive temperature rise could be attributable to greenhouse effects, although other possible causes include are: (1) anthropogenic greenhouse gases, (2) haze from cities, factories, and burning fields and forests, (3) irrigation that keeps the soil surface warmer at night, (4) warming of urban zones, which keeps the night temperature high. (5) no forest in urban areas (6) population density is high in urban areas etc.

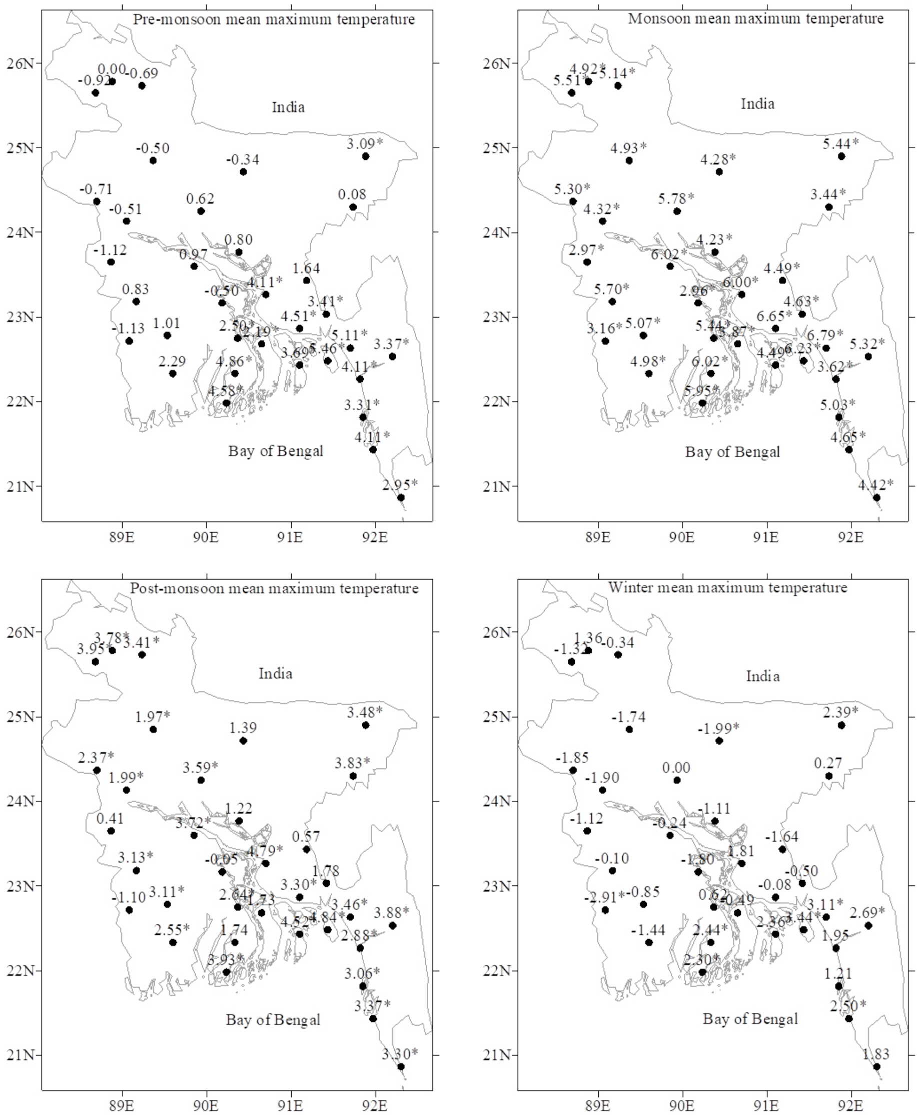

Fig. 5: Values of the statistics Z of the Mann-Kendall test for the seasonal means of maximum temperature during 1981-2020. Star (*) values indicate significant trends.

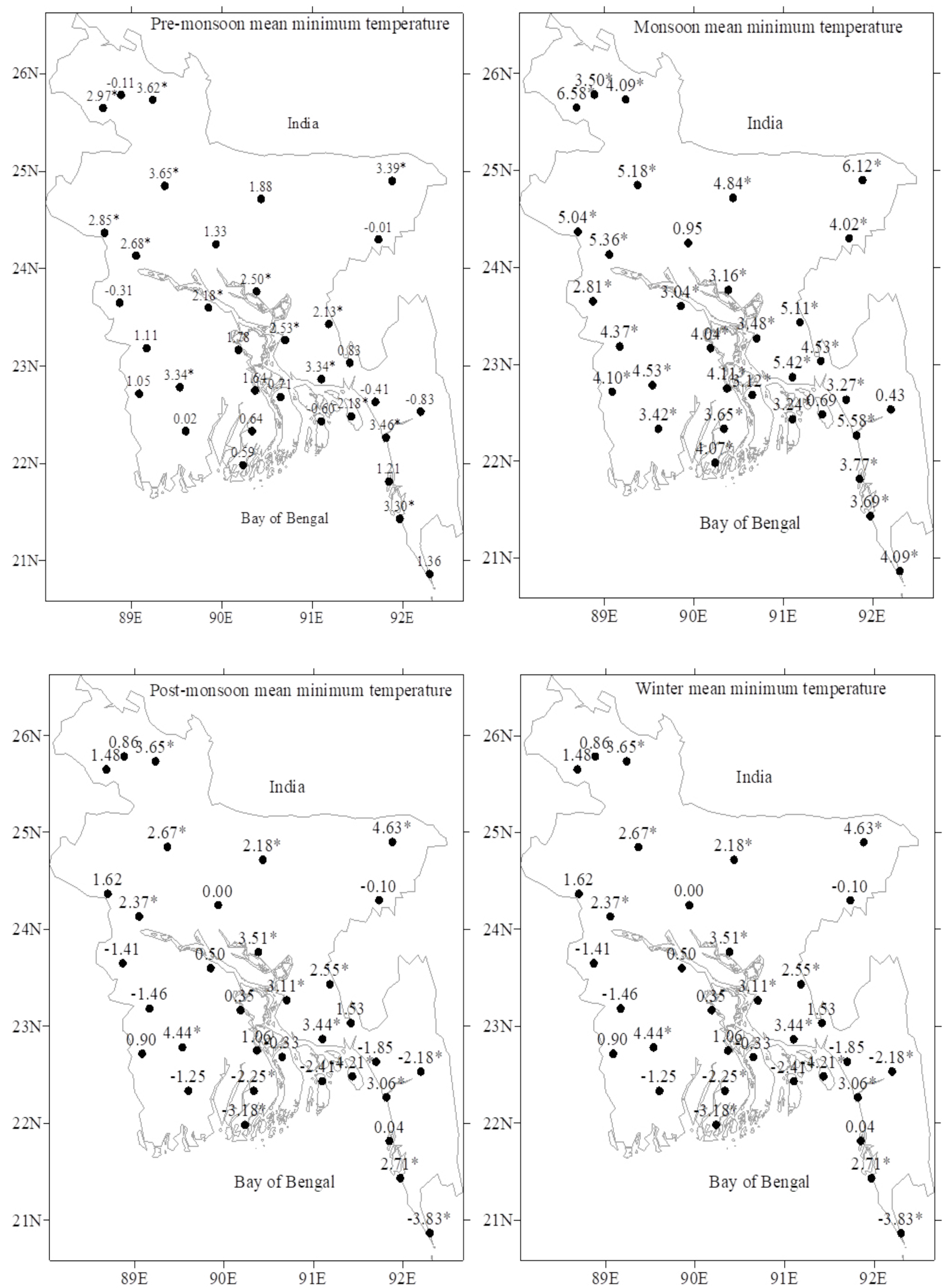

Fig. 6: Values of the statistics Z of the Mann-Kendall test for the seasonal means of minimum temperature during 1981-2020. Star (*) values indicate significant trends.

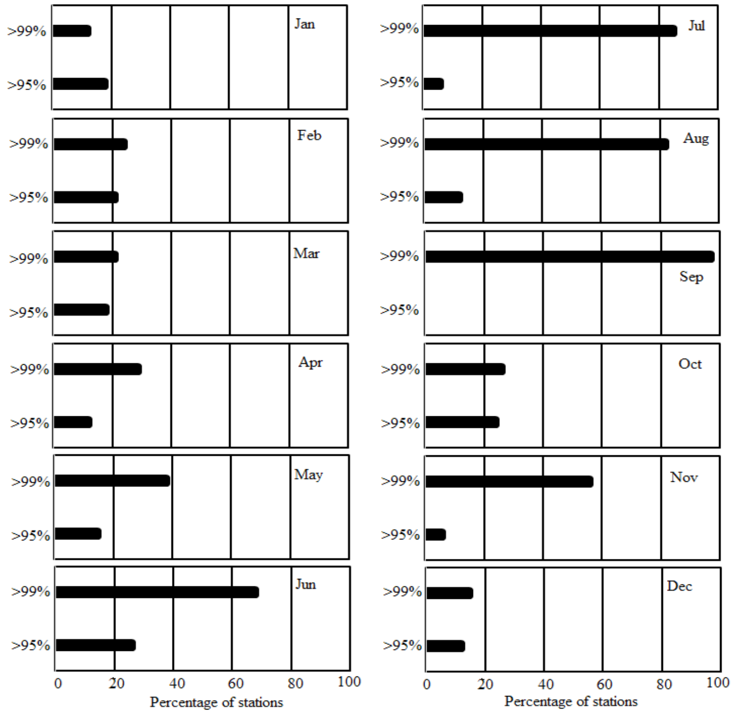

Fig. 7: The percentage of stations with significant trends in the monthly maximum temperature series by the Mann-Kendall test at the 95% and 99% confidence levels.

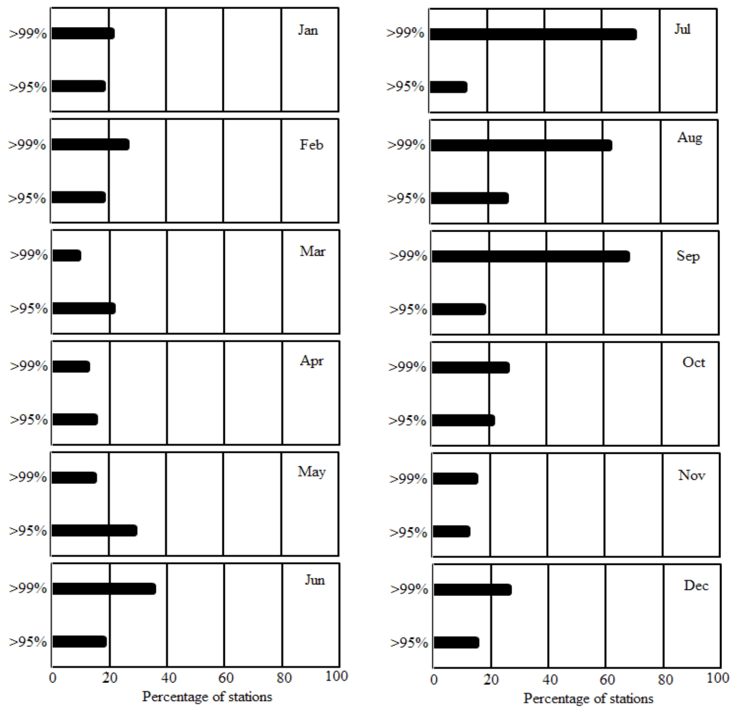

Fig. 8: The percentage of stations with significant trends in the monthly minimum temperature series by the Mann-Kendall test at the 95% and 99% confidence levels.

4. CONCLUSION

The annual, seasonal, and monthly mean maximum and mean minimum air temperature time series for 34 stations in Bangladesh were analysed for the period 1981–2020 in this study. On the basis of temperature data, the outcomes of the three statistical techniques are very comparable. Although maximum air temperature increased faster than minimum air temperature in most months and seasons, the results for the variables studied indicated similar positive trends. According to the linear regression technique, the significant increasing mean maximum air temperature trends at Patuakhali station are 0.08 °C/decade in February and 0.82 °C/decade in October. Furthermore, at Sandwip station in July, significant increasing mean minimum air temperature trends are 0.03 °C/decade, while at M. Court station in March, are 0.67 °C/decade. The highest monthly mean maximum and minimum air temperature time series value declines (decreases) were found over Mongla in January at -0.58 °C/decade and over Sandwip in January at -0.64 °C/decade, respectively.

In pre-monsoon, 47% of stations had significant increasing mean maximum air temperature trends, 100% in monsoon, 74% in post-monsoon, and 24% in winter season, respectively. Similarly, for pre-monsoon, monsoon, post-monsoon, and winter seasons, mean minimum air temperature was shown to be considerably increasing in 41, 91, 41, and 35% of the stations, respectively. As a result, in pre-monsoon and monsoon seasons mean maximum and minimum air temperature data exhibited higher increasing trends than the post-monsoon and winter seasons. On a monthly basis, in September and July had the most significant positive mean maximum and mean minimum air temperature trends, accounting for 97% and 71% of the total stations in the mean maximum and mean minimum air temperature trends series, respectively.

On the other hand, the number of stations with significant positive means maximum and mean minimum air temperature trends was lowest in January and March, respectively. Almost all of the monthly mean minimum air temperature series were significantly increased at Sylhet, Khulna, M. Court, and Chittagong stations, respectively, but the highest significant trends in the monthly mean maximum air temperature series were detected at Hatiya, Sandwip, and Sitakunda stations, respectively. In contrast, there were no significant positive or negative trends in the monthly mean minimum air temperature series at Tangail and Chuadanga stations. Additionally, more research in this area will be conducted in the future.

Vulnerability assessments, disaster management, enhanced structure design, institutional reform, and anti-extreme climate engineering are all viable adaption techniques in Bangladesh. Mitigation and adaptation to climate change should be included in any comprehensive climate policy.

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